Fishery Data Series No. 19-27

Estimating Salmon Abundance in the Kuskokwim River Using Sonar, 2017

by

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and

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November 2019

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	\$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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by
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ABSTRACT

In 2017, sonars were operated on the Kuskokwim River to estimate the abundance and run timing of Pacific salmon *Oncorhynchus* spp. following recommendations from a 2014–2016 feasibility study. After identifying a location with a suitable bottom profile, split-beam and imaging sonar were deployed on the gentle sloping left bank and an imaging sonar was deployed on the steep right bank. Species-specific fish passage abundance estimates were generated using a 3-step process. First, all fish passing the site were estimated, without regard to species. Second, species compositions were estimated and adjusted using selectivity parameters. Finally, species composition estimates were applied to total passage estimates to create species-specific abundance estimates. An unadjusted estimate of 2,531,397 fish passed the sonar site between June 1 and July 26. However, right bank vertical sonar coverage was incomplete in 2017 due to late installation of a spreader lens. An expansion based on 2016 and 2017 left bank counts was used to produce estimates of right bank missed passage by species. Despite adjustments, there were still substantial differences between sonar estimates and Kuskokwim River run reconstruction and mark–recapture projects estimates of Chinook salmon *Oncorhynchus tshawytscha* that may be due to abnormal river conditions in 2017 (i.e., low water levels).

Key words: Pacific salmon *Oncorhynchus* spp., Chinook salmon *Oncorhynchus tshawytscha*, chum salmon *O. keta*, sockeye salmon *O. nerka*, hydroacoustics, sonar, split-beam, ensonification, long range dual-frequency identification sonar, DIDSON, adaptive resolution imaging sonar, ARIS, gillnet, apportionment, Kuskokwim River, Alaska

INTRODUCTION

The Kuskokwim River supports runs of all 5 species of Pacific salmon *Oncorhynchus* spp. Sockeye salmon *O. nerka*, chum salmon *O. keta*, and several whitefish species historically supported a modest commercial fishery and Chinook salmon *O. tshawytscha* are a staple of one of the largest subsistence fisheries in Alaska. Most subsistence and all historical commercial harvest occur in the first 200 km of the Kuskokwim River and harvest opportunity is managed inseason (Figure 1). A test fishery operated by the Alaska Department of Fish and Game (ADF&G) near Bethel uses catch per unit effort (CPUE) indices to inform run strength and assist inseason management (Tiernan and Poetter 2015), whereas weir projects and aerial surveys provide postseason escapement estimates to key spawning tributaries (Liller 2017). In addition, several tagging projects have been conducted to assess run size and run timing of Chinook, chum, and coho salmon *Oncorhynchus kisutch* (Smith and Liller 2017; Schaberg et al. 2010; Liller et al. 2014). Currently, no existing projects provide inseason estimates of abundance, which is considered key data for successful management of harvest during the run. A 2014–2016 feasibility study determined that sonar could provide timely and accurate inseason abundance estimates for salmon migrating through the lower river harvest areas during typical river conditions (Brodersen et al. 2016; Birchfield et al. 2019).

The Kuskokwim River has an irregular history of sonar projects operating in the lower river. In 1980 and 1981, a feasibility study was conducted at a site 8 km upstream from Bethel, but results were inconclusive, and a full-scale project was not developed (Nickerson and Gaudet 1983). From 1988 to 1990, a feasibility project was operated near the same location, and from 1991 to 1995, the project produced daily passage estimates (Vaught and Molyneaux 1995). Early operations encountered problems including sub-optimal left bank profiles while using 1 transducer, surface ensonification due to a wide beam that resulted in low signal to noise ratios, and no access to low frequency sonar, which limited horizontal range due to attenuation (Vaught and Molyneaux 1995). A 3-year feasibility study was initiated in 1999 at a new site 26 km upstream from Bethel but only operated for a single season due to staffing shortages. Improvements in sonar technology over the last 2 decades, and the continuing need for additional inseason management tools, prompted renewed interest in using sonar to estimate salmon abundance in the lower Kuskokwim River.

A 2014–2016 feasibility study assessed using sonar, in combination with drift gillnetting, to estimate salmon abundance in the Kuskokwim River. Sites were reviewed in 2014 and 2015 based on bottom profiles and historical sonar locations. A preferred site near Church slough site was selected based on proximity to Bethel (20 river km), location downstream from most major salmon spawning tributaries, and historical site stability. A combination of split-beam and imaging sonar was optimal to enumerate fish passage and drift gillnet fishing along 3 corresponding horizontal zones apportioned counts. Depending on site conditions, sonar could ensonify up to 390 m of the 420 m span at the Church slough site. Consistent bottom profiles, successful drift gillnetting, and clear sonar images year-to-year indicate this site will remain a viable option to estimate mainstem fish passage (Brodersen et al. 2016; Birchfield et al. 2019).

This report presents results from the first year of full operation for the Kuskokwim River sonar in 2017.

OBJECTIVES

The primary project objective was as follows:

1) Provide managers with timely estimates and associated confidence intervals of daily and seasonal passage of adult Chinook, sockeye, chum, and coho salmon between June 1 and July 26.

The secondary project objective was as follows:

2) Collect daily climatic and hydrologic measurements representative of the study area between June 1 and July 26.

METHODS

STUDY DESIGN

Study Area

The Kuskokwim River is the second largest drainage in Alaska, flowing west approximately 730 km from the confluence of its east and north forks near Medfra to the Bering Sea. The glacially fed north fork originates northwest of Denali in the Kuskokwim Mountains and Alaska Range, bringing the total length to 1,130 km whereas the south fork flows out of the Alaska Range west of Mount Gerdine (Figure 1; Benke and Cushing 2005).

The sonar project was located just upriver from the confluence of the Kuskokwim River and Church Slough at river km 130 (20 river km upriver from Bethel). The river forms a single channel with a river width of 420 m at the sonar site (Figure 2). Right bank substrate was predominately coarse silt, with a slope of approximately 25°. The left bank had a gradual slope of approximately 2.6° and the substrate was muddy to fine silt.

River Bottom Surveys

Fish detection by sonar required a suitable bottom profile with minimal relief. Two series of bottom profiles were produced using a Hummingbird 998C SI[1] fathometer with GPS and side-scan sonar to determine viable sonar deployment locations. Preseason and inseason surveys were analyzed using a depth profiling program to produce river cross section summaries and determine temporal stability. Profiles were reviewed to determine optimal slope and bottom curvature. Optimal conditions are defined as smooth, slightly concave, with consistent left and right bank slopes.

Sonar Deployment and Operation

A long range dual-frequency identification sonar (DIDSON-LR) manufactured by Sound Metrics Corporation (SMC) was deployed on the left bank to ensonify the 0–20 m nearshore region (stratum 1 [LS1]; Table 1). Immediately adjacent to the DIDSON-LR, a digital split-beam echosounder system manufactured by Hydroacoustic Technology Inc. (HTI; model 244) operated at 120 kHz, was used with a split-beam transducer (HTI model 1.5° x 8° model) to ensonify the 20–100 m (stratum 2 [LS2]) and 100–300 m (stratum 3 [LS3]) ranges (Table 2). A 1.75-inch mesh net lead was deployed from shore approximately 2 m downriver and extended 5 m beyond the transducers to prevent fish from passing behind the sonar. The lead was angled approximately 20° upriver, marked with buoys, and secured with steel conduit Nurail joints, galvanized strainers, steel cable, leadline, and anchors.

An adaptive resolution imaging sonar (ARIS; SMC model 1200) was deployed on the steep right bank. The ARIS operated at 1.2 MHz to ensonify the 0–20 m range (stratum 1 [RS1]) and at 0.7MHz to ensonify the 20–40 m range (stratum 2 [RS2]). A 28° spreader lens was required to ensonify a greater range of the water column (Table 3). Spreader lens installation was delayed until July 5 in 2017. No lead was deployed on the right bank due to a very narrow (~5 m) and shallow (<1 m) shelf behind the sonar.

Sonar equipment required aiming after each deployment, pod movement, or if bottom profiles degraded (Table 4). The split-beam transducer was aimed remotely using a pair of rotators (HTI model 661) in conjunction with a rotator controller (HTI model 660) for remote tilt and pan settings. The ARIS was linked directly to a rotator (SMC model 1200-AR2) for remote tilt and roll settings, and the DIDSON-LR was manually tilted and panned using a custom aluminum mount. Aiming procedures were the same between all systems with a few exceptions. Echograms were recorded from the sonar while an operator tilted or panned the transducer in small increments (0.5–2.0° for HTI, 1.0–2.0° for ARIS) and used a manual crank to adjust the DIDSON-LR. Each aim was selected based on the prevalence of bottom returns throughout the stratum indicating consistent coverage across the full horizontal range. All settings were recorded on a paper form and sonar systems were updated to reflect new aims. Repositioning sonar was rarely necessary because water levels were low and stable in 2017 (Table 4).

Sonar equipment was operated daily and recorded 30 minutes of data during even hours in each ensonified zone. Starting at 0000 each day, RS1, LS1, and LS2 recorded for 30 minutes. At the bottom of the hour, RS2 and LS3 recorded for 30 minutes. Sonar recording periods were expanded to daily estimates of abundance. Previous research has shown that the difference

[1] Product names used in this report are included for scientific completeness, but do not constitute a product endorsement.

between abundance estimates from data collected at discrete intervals throughout the day, and data collected continuously over 24 hours, was minimal (Xie and Martens 2014; Melegari 2015). However, continuous data collections cost significantly more than discrete time sampling methods.

Technicians processed 30-minute sonar samples using custom software Echotastic 2.5 developed by ADF&G (Carl Pfisterer, Commercial Fisheries Biologist, ADF&G, Fairbanks) during 3 scheduled shifts: 0500–0830, 1530–1900, and 2100–0030 hours. Only upstream fish were marked. Each mark was saved as an individual record (including time and range from transducer) in a *.txt file for that bank and stratum. The total number of marks was recorded on a paper count form.

All counts were reviewed postseason for quality assurance. This involved a systematic review of 3,171 counted files. Each 30 minute sample was reviewed for accuracy and individual counter accuracy was summarized to improve future count training.

Drift Gillnet Fishing

A drift gillnet test fishery used a suite of 6 gillnet mesh sizes hung at a 2:1 ratio to apportion daily passage estimates by species (Table 5). Drift zones were corresponded to sonar strata: right bank nearshore (Zone 1), left bank nearshore (Zone 2), and left bank offshore (Zone 3; Figure 3). Gillnets were 25 fathoms in length (45.7 m) and 4.2–8.0 m in depth to match river depth. Zone 2 used the 4.2 m deep nets whereas Zones 1 and 3 required 8.0 m deep nets to sample the full water column. Test fishing occurred during 2 fishing periods. Drift Period 1 was 0900–1330 and Period 2 was 1500–1930 hours. During each period, 3 different mesh sizes were fished once per zone for a total of 9 drifts of varying durations. Mesh groupings remained consistent throughout the season and alternated between fishing periods daily (Table 6). Zone 1 fished for 6 minutes including half of set-out and pull-in times (~4 minute drift). Zones 2 and 3 drifts fished for 6 minutes at the beginning of the season but slow river velocity and lower overall passage in Zones 2 and 3 necessitated an increase of total drift times to between 7 and 12 minutes, depending on fish passage.

Biological Sampling

Drift gillnetting was used to collect species, sex, and length data. Fish were removed from gillnets as they were pulled into the boat and placed in a tote filled with fresh river water until the net was fully retrieved. All captured fish were identified to species. Species identification was accomplished using morphological and meristic traits. Common identifiers included mouth position, fin coloration, gum coloration, gill raker counts, and scale coloration, size and spotting (Mecklenburg et al. 2002). Length was collected using a fabric tape measure affixed to a wooden measuring cradle. Salmon species were measured to the nearest mm using mid eye to tail fork (METF) and all other species were measured using fork length. Morphological features including girth, kype development, and ovipositor presence/absence were examined to externally determine sex of all salmon species collected. All test fishery data, including drift information and biological data, were recorded on printed test fish forms and entered into a database. Fish were released at the discretion of samplers based on physical condition. Excessive bleeding, lethargy, or time out of the water contributed to the retention of individuals. Retained fish were distributed to local communities and recorded.

DATA ANALYSIS

Daily passage estimates were produced using a multi-component process consistent with ADF&G estimation methods used at other sonar projects (e.g., Lozori and McIntosh 2014):

1) Step 1 produced estimates of all fish passing the site without regard to species each day.
2) Step 2 estimated species composition collected during test fishing and adjusted composition using selectivity parameters applied to effort.
3) Step 3 applied species composition estimates to estimates of all fish passing the site to estimate species-specific abundance then summed across all days of passage to produce a cumulative passage estimate.

This process was completed for Chinook, chum, sockeye, coho, and pink salmon *O. gorbuscha* and other species. Unless otherwise specified, "other" species included humpback whitefish *Coregonus pidschian*, broad whitefish *C. nasus*, Bering cisco *C. laurettae*, least cisco *C. sardinella*, burbot *Lota lota*, inconnu *Stenodus leucichthys*, Dolly Varden *Salvelinus malma*, Arctic grayling *Thymallus arcticus*, northern pike *Esox lucius*, and longnose sucker *Catostomus catostomus*.

Passage Estimation

Sonar estimates were first stratified by bank and then by stratum. Let h_{dsp} denote the fraction of the hour sampled on day (d), for stratum (s) and sonar sample (p), let y_{dsp} denote the count for the same sample, and let n_{ds} denote the number of samples on day (d) and in stratum (s). The daily passage estimate ($\hat{y}_{ds}$) was calculated by averaging the hourly passage rates for the hours sampled and then multiplying as:

$$\hat{y}_{ds} = 24 \cdot \frac{\sum_{p=1}^{n} \frac{y_{dsp}}{h_{dsp}}}{n_{ds}}. \tag{1}$$

Treating the systematically sampled sonar counts as a simple random sample could yield an overestimate of the total variance because sonar counts are highly autocorrelated. To accommodate these data characteristics, a variance estimator, based on the squared differences of successive observations was employed (Wolter 1985). The variance for the passage estimate ($\hat{y}_{ds}$) was estimated using the number of samples in the day (n_{ds}), the fraction of the day sampled (f_{ds}), the hourly count (y_{dsp}), and the fraction of the hour sampled (h_{dsp}) as:

$$\hat{V}ar(\hat{y}_{ds}) = 24^2 \frac{1-f_{ds}}{n_{ds}} \frac{\sum_{p=2}^{n_{ds}} \left(\frac{y_{dsp}}{h_{dsp}} - \frac{y_{ds,p-1}}{h_{ds,p-1}} \right)^2}{2(n_{ds}-1)}. \tag{2}$$

Species Apportionment

Species proportions in Zone 1 were assigned to both the RS1 and RS2. Proportions in Zone 2 were used to apportion LS1 and LS2, and proportions in Zone 3 were used to apportion LS3 (Figure 4).

Species proportion estimates were calculated based on report units (u), encompassing 1 or more full days of sampling in a zone, and then applied to the daily sonar estimates. Any unique combination of day and zone with sufficient test fishery catch (i.e., at least 2 test fishing periods with 1 or more fish each and a combined minimum of 3 fish total) were assigned a unique report unit (u), and combinations without sufficient catch were pooled by assigning the same report unit across days (Table 7).

We defined *SO* as the time the gillnet was initially set out, *FO* as the time the net was fully set out, *SI* as the time the net started back in, and *FI* as the time the net was fully retrieved. Duration of the drift (j), in minutes (t), was calculated as:

$$t_j = \left(SI_j - FO_j\right) + \frac{\left(FO_j - SO_j\right)}{2} + \frac{\left(FI_j - SI_j\right)}{2}. \tag{3}$$

To estimate species proportions for report unit (u), the total effort (f) (in fathom-hours) of drift (j) using mesh size (m) during report unit (u) was calculated by multiplying the sampling time (t) for each drift by 25 fathoms and dividing by 60 minutes as:

$$f_{umj} = \frac{25 \cdot t_{umj}}{60}. \tag{4}$$

Then total effort (f) for each drift (j) of mesh size (m) was summed over each report unit as:

$$f_{um} = \sum_j f_{umj}. \tag{5}$$

The catch of each species (i) of length (l) associated effort was adjusted by applying a length-based selectivity parameter (S) derived from the Pearson T net selectivity model developed for the Yukon River (Appendix A1; Bromaghin 2005) as:

$$f'_{uil} = \sum_m \left(S_{ilm} \cdot f_{um}\right). \tag{6}$$

The catch of each species of length (l) in each report unit (u) was summed across all mesh sizes as:

$$c_{uil} = \sum_m c_{uilm}. \tag{7}$$

The CPUE of the catch of each species of length (l) was calculated as:

$$CPUE'_{uil} = \frac{c_{uil}}{f'_{uil}}. \tag{8}$$

The proportion (p) of species (i), during report unit (u), was estimated as the ratio of the CPUE for species (i) to the CPUE of all species combined as:

$$\hat{p}_{ui} = \frac{\sum_l CPUE'_{uil}}{\sum_{i,l} CPUE'_{uil}}. \tag{9}$$

Variance was estimated by dividing the squared differences of the proportion (p) of each test fishing period (g) for each day (d) within the report unit (u) and the proportion for the report unit by the number of test fishing periods (n_u) as:

$$\hat{V}ar(\hat{p}_{ui}) = \frac{\sum_{d,g}(\hat{p}_{ui} - \hat{p}_{udgi})^2}{n_u(n_u - 1)}. \tag{10}$$

Species Passage Estimates

The passage of species (i) in stratum (s) was estimated for each day as the product of the species proportion (Equation 10) for the report unit (u) containing day (d) in stratum (s) and the total sonar passage for the day (Equation 1) as:

$$\hat{y}_{dsi} = \hat{y}_{ds} \cdot \hat{p}_{udi}. \tag{11}$$

Except for the timing of sonar and test fishery periods, sonar-derived estimates of total fish passage were considered independent of test fish-derived estimates of species proportions. Therefore, the variance of their product (daily species passage estimates by stratum $\hat{y}_{di}$) was estimated as the variance of the product of 2 independent random variables (Goodman 1960) as:

$$\hat{V}ar(\hat{y}_{dsi}) = \hat{y}_{ds}^2 \cdot \hat{V}ar(\hat{p}_{ui}) + \hat{p}_{ui}^2 \cdot \hat{V}ar(\hat{y}_{ds}) - \hat{V}ar(\hat{y}_{ds}) \cdot \hat{V}ar(\hat{p}_{ui}). \tag{12}$$

Daily fish passage for each species was calculated by summing across strata as:

$$\hat{y}_{di} = \sum_{s} \hat{y}_{dsi}. \tag{13}$$

Cumulative fish passage for each species was calculated by summing daily passage across days as:

$$\hat{y}_i = \sum_{d} \hat{y}_{di}. \tag{14}$$

Passage estimates are assumed independent between reporting units, so the total variance for species (i) was estimated by the sum of their variances as:

$$\hat{V}ar(\hat{y}_i) = \sum_{ds} \hat{V}ar(\hat{y}_{dsi}). \tag{15}$$

Assuming normally distributed errors, 95% confidence intervals were calculated as:

$$95\%\ \text{CI} = \hat{y}_i \pm 1.96\sqrt{\hat{V}ar(\hat{y}_i)}. \tag{16}$$

All statistical analyses were conducted using the computing environment R (R Core Team 2015).

Missed Passage Estimation

In 2017, total passage was unavailable June 1, 2, 5–15, 19–30, and July 1–4 because the sonar on one bank was inoperable or operation was limited (Table 8). Passage during those days was estimated by expanding single bank counts using average daily ratios of fish passage by bank and stratum from dates in which all sonar were operational during the 2016 and 2017 seasons. Total passage by day and stratum were estimated as follows.

Passage ratios ($\hat{R}$) by bank (b) on day (d) during which all sonar were operational were calculated as the estimated passage by bank divided by total daily estimated passage as:

$$\hat{R}_{db} = \frac{\hat{y}_{db}}{\hat{y}_d}. \tag{17}$$

Average passage ratios ($\overline{R}$) by bank across all days (n) during which all sonar were operational were calculated as:

$$\overline{R}_b = \frac{\sum_d R_{db}}{n}. \tag{18}$$

To generate an estimate of total daily passage ($\hat{Y}_d$) when sonar was inoperable or sonar coverage was incomplete, the daily passage estimate ($\hat{y}_d$) from the operational bank was divided by the average passage ratio for that bank as:

$$\hat{Y}_{d'} = \frac{\hat{y}_{db}}{\overline{R}_b}. \tag{19}$$

Passage ratios by stratum (s) and day during which all sonar were operational were calculated as the daily estimated passage by stratum divided by the daily estimated passage across all strata as:

$$\hat{R}_{ds} = \frac{\hat{y}_{ds}}{\hat{y}_d}. \tag{20}$$

Average passage ratios by strata across all days when all sonar were operational was calculated as:

$$\overline{R}_s = \frac{\sum_d R_{ds}}{n}. \tag{21}$$

Daily missed passage by stratum ($\hat{Y}_{ds'}$) was estimated as the product of the total daily passage estimate and the average daily passage ratio estimate by stratum as:

$$\hat{Y}_{ds'} = \hat{Y}_{d'} \cdot \overline{R}_s. \tag{22}$$

Variance of missed passage by stratum was estimated using a parametric bootstrap simulation with 1,000 replicates (n) (Efron 1982). The uncertain parameters $\overline{R}_b$ and $\overline{R}_s$ associated with missed passage were modeled, denoted in subsequent equations with an asterisk (*). With each bootstrap replicate, denoted with subscript (z), a probable value for each parameter was drawn from an assumed distribution and a bootstrap estimate of simulated abundance was calculated (Equations 18–23).

Average passage ratios by bank were assumed to have a lognormal distribution (*LN*) and were modeled as:

$$\overline{R}^{*}_{b(z)} \sim LN(\ln \overline{R}_b, \sigma_{\ln(\overline{R}_b)}) . \tag{23}$$

Average passage ratios by stratum were assumed to have a lognormal distribution and were modeled as:

$$\overline{R}^{*}_{s(z)} \sim LN(\ln \overline{R}_s, \sigma_{\ln(\overline{R}_s)}) . \tag{24}$$

The average bootstrap estimate of simulated missed passage ($Y^{*}_{ds(z)'}$) calculated as $\sum Y^{*}_{ds(z)'} \big/ 1{,}000$ was used to approximate variance of the mark–recapture estimate, using the following equation:

$$Var(\hat{Y}^{*}_{ds(z)'}) = \frac{\sum (\hat{Y}^{*}_{ds(z)'} - \overline{Y}^{*}_{ds(z)'})^2}{(n-1)} . \tag{25}$$

Estimated variance was incorporated into total variance by species using Goodman's (1960) variance of the product of 2 random variables by replacing variance due to passage estimation (Equation 13).

Revised daily passage estimates by stratum for each species were generated by applying the species proportion estimate from report unit (*u*) containing day (*d*) (Equation 10) to updated daily passage estimates by stratum as:

$$\hat{Y}_{dsi'} = \hat{Y}_{ds'} \cdot \hat{p}_{udi} . \tag{26}$$

Updated cumulative fish passage for each species was calculated by summing daily passage across days and strata as:

$$\hat{Y}_{i'} = \sum_{d} \sum_{s} \hat{Y}_{dsi'} . \tag{27}$$

Finally, new confidence intervals were calculated assuming normally distributed errors with 95% confidence intervals:

$$95\%\ \text{CI} = \hat{Y}_{i'} \pm 1.96 \sqrt{\hat{V}ar(\hat{Y}_{i'})} . \tag{28}$$

Climatologic and Hydrologic Observations

Water temperature was sampled using HOBO meters installed at the base of the sonar tripods, approximately 1 m deep in the water (Appendix B1). Atmospheric conditions (air temperature, precipitation, cloud cover, and wind) were also recorded during sonar counting shifts for metadata purposes.

RESULTS

River Bottom Surveys

Bottom profiles continued to exhibit optimal conditions for sonar operation. Initial surveys and midseason reviews indicated a stable site profile both inseason and between years (Figures 5, 6, and 7; Birchfield et al. 2019). There is sufficient evidence to conclude that bottom profiles will remain stable at the Church Slough sonar site.

Sonar Deployment and Estimates

The Kuskokwim River sonar project operated June 1–July 26. The ARIS operated 52.33 days, DIDSON for 47.17 days, and split-beam for 47.58 days out of approximately 56 days of project operations. Hardware issues delayed DIDSON deployment until June 2 and split-beam deployment until June 3 (Table 4). As described by Brodersen (et al. 2016), fish exhibited broad vertical distribution along the right bank in the Kuskokwim River. In order to accurately estimate right bank passage, the ARIS beam was vertically widened from 14° to 28° using a spreader lens; however, the spreader lens installed until after the unit was removed for midseason maintenance on July 4 (Table 4). This resulted in underestimation of right bank counts.

An unadjusted estimate of 2,531,397 fish passed the sonar site between June 1 and July 26; right bank nearshore was 1,276,296 fish (50.42%), left bank nearshore was 816,998 fish (32.23%), and left bank offshore was 438,104 fish (17.31%; data on file with Kuskokwim Research Group, ADF&G Division of Commercial Fisheries, Fairbanks). Median range of fish passage along the left banks was 40.00 m from June 2 to July 26. Median range of passage along the right bank was 6.40 m from June 1 to July 26 (Figure 8).

Drift Gillnet Fishing

A total of 3,549 fish were caught during drift gillnet fishing; 153 Chinook, 1,109 sockeye, 1,100 chum, 76 pink, 33 coho, and 1,078 others. Of the captured fish, 19.9% were retained as mortalities and distributed to residents to help meet subsistence needs (Table 9). In 2017, there was 1 interruption to full coverage from June 16 to June 18 when all 6.5-inch mesh 8.0 m deep nets were out of operation. The effects on apportionment were considered minimal because the sonar project apportionment methods are specifically designed to handle loss of mesh sizes.

Species Passage Estimates

To accurately describe species-specific passage estimates, an expansion was conducted on right bank passage counts. This was accomplished using June 10 to July 25, 2016, and July 5 to July 26, 2017 passage estimates to conduct a parametric bootstrap analysis by stratum to expand right bank counts in 2017 (Table 10). Adjusted Chinook salmon passage estimate was 79,471 fish (95% CI 58,195–100,748; Figure 9). Sockeye salmon passage estimate was 1,024,381 fish (95% CI 902,073–1,146,690; Figure 10). Chum salmon passage estimate was 728,081 fish (95% CI 641,832–814,330; Figure 11). Pink salmon passage estimate was 69,203 fish (95% CI 44,893–93,513; Figure 12). Other species totaled 876,456 fish (95% CI 732,549–1,020,363; Figure 13). Coho salmon passage estimate was unchanged because the spreader lens was operational during all coho salmon passage (Figure 14).

To compare the estimated effect of spreader lens deployment, a comparison between unexpanded and expanded estimates was conducted for each species. Right bank expansions resulted in an increase of 25.83% Chinook salmon, 14.32% sockeye salmon, 10.39% chum salmon, 1.00% pink salmon, and 6.16% other species (data on file with Kuskokwim Research Group, ADF&G Division of Commercial Fisheries, Fairbanks).

DISCUSSION

Most inseason indicators of sonar operation and environmental conditions were positive in 2017. River bottom profiles indicated the best horizontal coverage since project inception. Low water levels and water velocity may have resulted in minimal scouring at the site. Sonar pod deployment locations were almost identical to 2016 and bottom profiles remained uniform year-to-year.

Although the split-beam and DIDSON sonar experienced a slightly delayed deployment on June 2, the effect of late deployment was considered negligible and the left bank sonar operated every day with minimal interruption. Improvements to split-beam signal-to-noise ratios allowed an extension of left bank offshore strata to within 30 m of right bank stratum (350 m) for the last 8 days of operation. This exceptional range may have been due to low sediment loads; however, increased passage in the 250+ m range indicated future coverage should extend to 300 m as a new minimum.

The ARIS system was deployed on schedule and operated every day, but the 28° spreader lens was not installed until the unit was examined for midseason maintenance on July 4. Vertical distribution analysis in 2015 showed the spreader lens was integral to accurate passage assessment on the right bank (Brodersen et al. 2016). To compensate for missed passage, an analysis was conducted using 2016 and 2017 data to estimate daily passage based on left bank passage. The expansion led to increased estimated abundance that ranged between 1.00% (pink salmon) and 25.83% (Chinook salmon).

The resulting expansion of right bank values was the best analysis of cumulative passage that could be attempted using available data. With that in mind, it is an estimate using data from June 1 to July 4 to estimate total daily passage with 2016 and 2017 bank ratios. This was not ideal because bank ratios fluctuate both inter- and intra-annually. It must be noted that adjusted estimates probably differ from true values and are probably an underestimation of all species in 2017. Future passage estimates could be used to improve bank ratio data for this year, but it is imperative that a spreader lens be installed in future years for project success.

Increases in drift duration and consistent net coverage resulted in perceived successful gillnet operations. There were 3 days during which a single mesh size (6.5 inch) was not fished in Zone 3. Despite strong internal measures of success, there were significant discrepancies between sonar Chinook estimates and Kuskokwim River run reconstruction, weirs, aerial surveys and Chinook tagging estimates. Due to corroborating estimates among all other projects, it is clear Chinook salmon estimates were inaccurate in 2017. Because passage variance makes up so little of project estimates, the discrepancies were probably due to issues with apportionment.

There were several potential factors that probably influenced apportionment in 2017. The 2017 season had one of the lowest water levels in recent history which resulted in low sediment loads, narrower channel width, and warmer surface water (USGS 2017; Appendices B1–B2). It is unknown what effect these changes had on species-specific distribution, but traditional knowledge described by local elders during meetings of the Kuskokwim Salmon Management Working Group indicated Chinook salmon run deeper and later during low water years. Water conditions in 2017 pointed to the possibility of a similar phenomenon when Chinook displayed later run timing than historical observations (Smith and Liller 2018), and the mid-river stratum (LS3) experienced high passage in the 200–300 m range. In addition, LS3 is a broad zone, encompassing 4 to 5 net lengths, and may include horizontally stratified species composition. Increasing water clarity may have resulted in size-based gillnet avoidance (i.e., larger fish avoiding nets more successfully than smaller fish; Breck and Gitter 2011). Without estimates of abundance for all species in the Kuskokwim River, it was difficult to determine if there was significant missed total passage due to sonar detection limitations.

There are a few steps that could be taken in future years to improve project performance and address some of these potential issues:

- Future studies could include turbidity and local water level trends to contextualize sonar counts with environmental conditions over multiple years (Appendix B3).
- A postseason comparative analysis between species length compositions at the sonar and weir projects could rule out any size-based gillnet avoidance.
- Mobile DIDSON review was conducted from a boat on the Yentna, Kenai, and Copper Rivers to estimate missed passage by imaging and/or split beam sonar (Maxwell et al. 2013). A similar review would quantify total missed passage of each sonar system.

Comparative analyses aside, project operation dates and design still appear adequate to describe seasonal passage of Chinook, sockeye, and chum salmon during typical Kuskokwim River conditions. Further analysis may be required before, during, and after extreme water level events to better understand species-specific interactions during atypical conditions. With proper deployment, operation, and environmental context, sonar can provide accurate inseason estimates of run timing and total passage for management of Kuskokwim River salmon stocks.

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TABLES AND FIGURES

Table 1.–Technical specifications for the long-range dual-frequency identification sonar (DIDSON-LR) on the Kuskokwim River left bank nearshore stratum (LS1), 2017.

		Value
Nominal settings		
	Mode	Identification
	Operating frequency (MHz)	0.7
	Beam dimensions (height x width)	14° x 0.6°
	Number of beams	48
	Field of view (horizontal)	29º
Sample settings		
	Start range (m)	0.83
	Window length (LS1; m)	20.01
	Range bin size (mm)	39
	Pulse length (µs)	46
	Frame rate (f/s)	5

Table 2.–Technical specifications for the split beam (SB) sonar in the Kuskokwim River left bank mid-range and offshore strata (LS2 and LS3), 2017.

Component	Setting	Stratum	Setting
Transducer	Beam dimensions (height x width)		1.5° x 8.0°
Echosounder	Transmit power (dB)		20
	Receiver gain (dB)		-6
	Source level (dB)		216.5
	Through-system gain (dB)		-172.4
	Pulse width (ms)		0.4
	Blanking range (m)		2
	Time varied gain (TVG)		40 log(R)
	Ping rate (pps)	LS2	7
		LS3	2.5
	Range (m)	LS2	20–100
		LS3	100–300

Table 3.–Technical specifications for the adaptive resolution imaging sonar (ARIS) in the Kuskokwim River right bank nearshore and offshore strata (RS1 and RS2), 2017.

Setting	Stratum	Value
Beam dimensions (height x width)		28° x 0.6°
Field of view (horizontal)		28°
Frequency (MHz)	RS1	1.2
	RS2	0.7
Transmit power (dB re 1 µPa at 1 m)		216.6
Receiver gain (dB)		20
Samples/beam		1024
Range start (m)		0.7
Frame rate (f/s)	RS1	11.2
	RS2	5.0
Range (m)	RS1	0.8–20.3
	RS2	20.3–40.1

Table 4.–Kuskokwim sonar event log, 2017.

			End angle in degrees[a]		
Date	Sonar	Event	S1	S2	S3
5/31	ARIS	Initial aim (tilt is reversed, negative is up)	-20.0	-10.0	
6/2	DIDSON	Initial aim after DIDSON replaced with spare			
6/3	SB	Initial aim		3.3	4.4
6/7	ARIS	Moved pod	-25.0	-2.0	
6/15	SB	Tilt review		3.6	4.6
6/28	ARIS	Tilt review	-9.0	-5.0	
7/3	SB, ARIS	Tilt review (ARIS no change)		3.6	5.0
7/5	ARIS	Cleaned lens, fixed reversed tilt, spreader lens added	-21.0	-15.0	
7/6	ARIS	Pod settled, aim reviewed, no auto-tilt	-25.0	-25.0	
7/7	ARIS	Re-aimed after auto-tilt issue resolved	-23.0	-15.0	
7/10	SB	Pan review		4.1	4.0
7/11	DIDSON	Generator shut down, lens cleaning			
7/16	SB, DIDSON	Moved SB, replaced DIDSON cable		3.5	4.1
7/19	SB, DIDSON	SB moved for water level		2.1	2.6
7/22	ARIS	Tilt review	-24.5	-15.0	
7/24	SB, DIDSON	Moved pod		5.0	5.1

Note: No height adjustments were necessary following initial deployment. After hardware changes aim was adjusted, as needed.

[a] DIDSON tilts are manual and do not have a measured angle. Transducer angles cannot be precisely compared between seasons or aims because pod placement and transducer zero angles may change between installations.

Table 5.–Specifications for drift gillnets used for test fishing at the Kuskokwim River sonar project, 2017.

Stretch mesh size			Meshes deep	Depth	Length
(in)	(mm)	Twine size	(md)	(m)	(fathoms)
2.75	70	50	131	7.9	25
2.75	70	50	67	4.1	25
4.00	102	50	90	7.9	25
4.00	102	50	45	4.0	25
5.25	133	63	69	7.9	25
5.25	133	63	35	4.0	25
6.50	165	73	56	8.0	25
6.50	165	73	28	4.0	25
7.50	191	83	48	7.9	25
7.50	197	83	25	4.3	25
8.50	216	93	43	8.0	25
8.50	216	93	22	4.1	18[a]

[a] The shallower 8.5-inch net was incorrectly measured for length during fabrication; however, test fishery apportionment accounts for net length in effort.

Table 6.–Schedule for drift gillnets used for test fishing by period and day at the Kuskokwim River sonar project, 2017.

Period	Odd day mesh size (in)	Even day mesh size (in)
1	4.00	2.75
	6.50	5.25
	8.50	7.50
2	2.75	4.00
	5.25	6.50
	7.50	8.50

Table 7.–Reporting units of zones pooled for the Kuskokwim River sonar project, 2017.

<table>
<tr><th rowspan="2">Date</th><th rowspan="2">Right bank (Zone 1)</th><th colspan="2">Left bank</th><th rowspan="2">Reason for pooling [a]</th></tr>
<tr><th>Nearshore (Zone 2)</th><th>Offshore (Zone 3)</th></tr>
<tr><td>6/1</td><td rowspan="4">100</td><td rowspan="2">200</td><td rowspan="2">300</td><td></td></tr>
<tr><td>6/2</td><td>ICS</td></tr>
<tr><td>6/3</td><td rowspan="2">201</td><td rowspan="2">301</td><td></td></tr>
<tr><td>6/4</td><td>IC, ICS</td></tr>
<tr><td>6/5</td><td rowspan="3">101</td><td rowspan="2">202</td><td rowspan="2">302</td><td></td></tr>
<tr><td>6/6</td><td>ICS</td></tr>
<tr><td>6/7</td><td></td><td rowspan="2">303</td><td>IC</td></tr>
<tr><td>6/8</td><td rowspan="2">102</td><td rowspan="2">204</td><td>IC</td></tr>
<tr><td>6/9</td><td rowspan="2">304</td><td>IC</td></tr>
<tr><td>6/10</td><td rowspan="2">103</td><td></td><td>IC</td></tr>
<tr><td>6/11</td><td></td><td></td><td>IC</td></tr>
<tr><td>6/12</td><td rowspan="2">104</td><td rowspan="2">207</td><td rowspan="2">306</td><td></td></tr>
<tr><td>6/13</td><td>IC, ICS</td></tr>
<tr><td>6/14</td><td rowspan="2">105</td><td rowspan="3">208</td><td rowspan="3">307</td><td></td></tr>
<tr><td>6/15</td><td>IC</td></tr>
<tr><td>6/16</td><td></td><td>IC</td></tr>
<tr><td>6/17</td><td></td><td></td><td rowspan="2">308</td><td></td></tr>
<tr><td>6/18</td><td></td><td></td><td>IC</td></tr>
<tr><td>6/19</td><td></td><td></td><td></td><td></td></tr>
<tr><td>6/20</td><td></td><td rowspan="2">212</td><td></td><td></td></tr>
<tr><td>6/21</td><td></td><td></td><td>IC</td></tr>
<tr><td>6/22</td><td></td><td rowspan="2">213</td><td></td><td></td></tr>
<tr><td>6/23</td><td></td><td></td><td>IC</td></tr>
<tr><td>6/24</td><td></td><td></td><td></td><td></td></tr>
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<tr><td>6/27</td><td></td><td></td><td></td><td></td></tr>
<tr><td>6/28</td><td></td><td></td><td></td><td></td></tr>
<tr><td>6/29</td><td></td><td></td><td></td><td></td></tr>
<tr><td>6/30</td><td></td><td></td><td></td><td></td></tr>
</table>

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Table 7.–Page 2 of 2.

Date	Right bank (Zone 1)	Left bank Nearshore (Zone 2)	Left bank Offshore (Zone 3)	Reason for pooling [a]
7/1				
7/2				
7/3				
7/4				
7/5				
7/6				
7/7				
7/8				
7/9				
7/10				
7/11				
7/12				
7/13				
7/14				
7/15				
7/16				
7/17				
7/18				
7/19				
7/20				
7/21				
7/22	142			
7/23				IC
7/24	143			
7/25			345	IC
7/26				IC
7/27				
7/28				
7/29				
7/30				
7/31				

Note: Gaps in dates indicate periods of no pooling.

[a] IC indicates that zones were pooled across days when there was insufficient catch in the test fishery for variance estimation. ICS indicates that zones were pooled across strata.

Table 8.–Periods of inoperable sonar or incomplete sonar coverage by stratum when known bank passage ratios exceeded historical average passage ratios.

Date	RBS1	RBS2	LBS1	LBS2	LBS3
6/1				IS	
6/2					
6/3					
6/4					
6/5					
6/6					
6/7					
6/8					
6/9					
6/10	SL				
6/11					
6/12					
6/13					
6/14					
6/15					
6/16					
6/17					
6/18					
6/19					
6/20					
6/21					
6/22					
6/23					
6/24	SL				
6/25					
6/26					
6/27					
6/28					
6/29					
6/30					

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Table 8.–Page 2 of 2.

<table>
<tr><th>Date</th><th>RBS1</th><th>RBS2</th><th>LBS1</th><th>LBS2</th><th>LBS3</th></tr>
<tr><td>7/1</td><td colspan="2" rowspan="4">SL</td><td></td><td></td><td></td></tr>
<tr><td>7/2</td><td></td><td></td><td></td></tr>
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<tr><td>7/19</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>7/20</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>7/21</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>7/22</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>7/23</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>7/24</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>7/25</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>7/26</td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>7/29</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>7/30</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>7/31</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Note: IS denotes passage in these strata were estimated due to inoperable sonar. SL denotes passage in these strata were estimated due to spreader lens absence and passage in these strata (relative to total passage) did not already exceed historical average known passage ratios.

Table 9.–Number of fish captured and retained in the Kuskokwim River sonar test fishery, 2017.

Total catch

	Chinook	Sockeye	Coho	Pink	Chum	Cisco	Broad	Humpback	Others[a]	Total
June	100	334	0	1	321	29	6	176	29	996
July	53	775	33	75	779	594	12	208	24	2,553
Total	153	1,109	33	76	1,100	623	18	384	53	3,549

Fish retained

	Chinook	Sockeye	Coho	Pink	Chum	Cisco	Broad	Humpback	Others[a]	Total
June	8	99	0	1	75	0	1	15	0	199
July	3	155	2	4	159	114	2	70	0	509
Total	11	254	2	5	234	114	3	85	0	708

Proportion retained

	Chinook	Sockeye	Coho	Pink	Chum	Cisco	Broad	Humpback	Others[a]	Total
June	8.0%	29.6%	0.0%	100.0%	23.4%	0.0%	16.7%	8.5%	0.0%	20.0%
July	5.7%	20.0%	6.1%	5.3%	20.4%	19.2%	16.7%	33.7%	0.0%	19.9%
Total	7.2%	22.9%	6.1%	6.6%	21.3%	18.3%	16.7%	22.1%	0.0%	19.9%

[a] Includes longnose sucker, northern pike, and Arctic grayling.

Table 10.–Adjusted daily and total passage at the Kuskokwim River sonar project, 2017.

Date	Chinook	Sockeye	Chum	Coho	Pink	Other	Total
6/1	318	0	0	0	0	1,451	1,768
6/2	417	0	0	0	0	1,813	2,229
6/3	190	0	0	0	0	2,475	2,665
6/4	214	0	0	0	0	2,973	3,187
6/5	2,060	0	0	0	0	2,484	4,544
6/6	2,364	0	0	0	0	2,842	5,206
6/7	2,372	0	0	0	0	6,185	8,556
6/8	1,550	0	0	0	0	6,518	8,069
6/9	1,555	88	0	0	0	5,608	7,251
6/10	1,768	635	1,235	0	0	3,541	7,179
6/11	583	0	2,407	0	0	4,828	7,818
6/12	1,021	1,189	736	0	0	3,178	6,124
6/13	1,201	1,398	846	0	0	3,685	7,129
6/14	388	910	1,058	0	0	4,725	7,081
6/15	430	1,022	1,185	0	0	5,324	7,962
6/16	0	5,804	700	0	0	6,554	13,058
6/17	989	1,392	3,999	0	0	18,285	24,665
6/18	565	7,877	3,311	0	0	12,711	24,464
6/19	2,637	6,672	8,114	0	0	6,875	24,298
6/20	211	11,997	2,457	0	0	14,096	28,762
6/21	1,437	8,253	5,629	0	0	10,682	26,000
6/22	5,287	4,821	5,783	0	0	7,597	23,488
6/23	3,454	9,584	3,172	0	0	5,649	21,858
6/24	1,755	9,553	14,683	0	0	4,633	30,624
6/25	2,546	4,832	9,360	0	0	10,515	27,253
6/26	2,781	18,437	21,162	0	0	7,913	50,293
6/27	3,860	11,681	24,868	0	0	4,759	45,167
6/28	2,593	44,010	29,857	0	702	14,589	91,751
6/29	2,924	30,328	28,817	0	0	18,549	80,618
6/30	1,367	52,836	21,028	0	0	9,504	84,735

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Table 10.–Page 2 of 2.

Date	Chinook	Sockeye	Chum	Coho	Pink	Other	Total
7/1	383	27,169	27,813	0	0	9,754	65,118
7/2	230	40,897	15,240	0	0	4,748	61,114
7/3	217	34,016	18,370	0	312	5,753	58,668
7/4	1,600	25,104	29,868	0	884	13,850	71,306
7/5	4,856	41,773	42,260	0	2,200	8,208	99,297
7/6	4,967	41,659	44,832	0	2,770	18,483	112,711
7/7	4,611	73,632	36,792	0	1,053	26,453	142,541
7/8	1,157	74,970	28,259	0	0	17,445	121,831
7/9	3,213	68,649	33,816	0	0	30,164	135,842
7/10	1,887	48,451	23,045	0	1,253	35,842	110,478
7/11	1,893	70,909	24,123	0	2,443	36,441	135,809
7/12	1,888	53,106	22,409	0	10,224	34,490	122,117
7/13	0	38,717	31,794	0	5,092	50,878	126,481
7/14	0	20,476	23,706	0	4,679	58,154	107,015
7/15	0	19,769	35,128	0	5,955	33,514	94,366
7/16	1,055	21,056	21,120	0	7,770	37,171	88,172
7/17	674	6,772	10,863	0	0	44,889	63,198
7/18	256	10,219	10,016	0	2,265	30,755	53,511
7/19	279	14,338	16,899	487	5,107	32,755	69,865
7/20	0	11,197	4,574	2,541	3,321	28,293	49,926
7/21	0	8,281	8,830	789	2,157	20,822	40,879
7/22	398	12,697	5,169	561	4,266	16,762	39,853
7/23	335	8,221	3,787	764	2,140	21,692	36,939
7/24	419	6,389	9,655	3,841	1,644	16,973	38,921
7/25	317	7,318	5,452	3,159	1,236	13,584	31,066
7/26	0	5,279	3,855	9,243	1,731	18,045	38,153
Total	79,471	1,024,381	728,081	21,385	69,203	876,456	2,798,978
SE	10,855	62,402	44,005	6,229	12,403	73,422	NA
CV(%)	13	6	6	29	18	7	NA
Lower 95	58,195	902,073	641,832	9,176	44,893	732,549	NA
Upper 95	100,748	1,146,690	814,330	33,594	93,513	1,020,363	NA

Note: Adjustments were based on bank passage proportions in 2016 and 2017. Values above the top box represent the first quartile, the top box represents the second quartile, the bottom box represents the third quartile and all values below the boxes represent the fourth quartile.

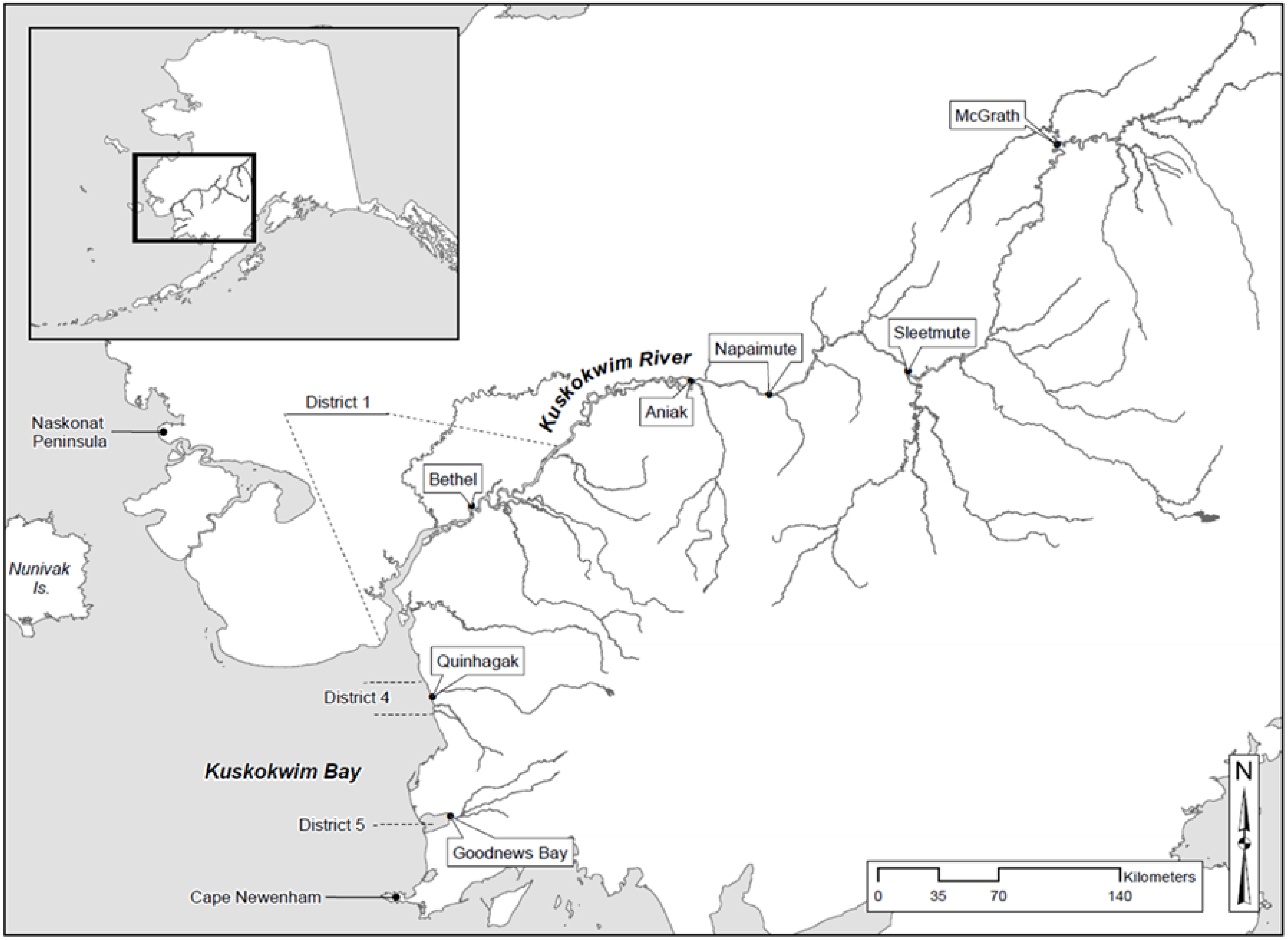


Figure 1.–The Kuskokwim Management Area, including Kuskokwim Bay, the Kuskokwim River, and select commercial fishing districts.

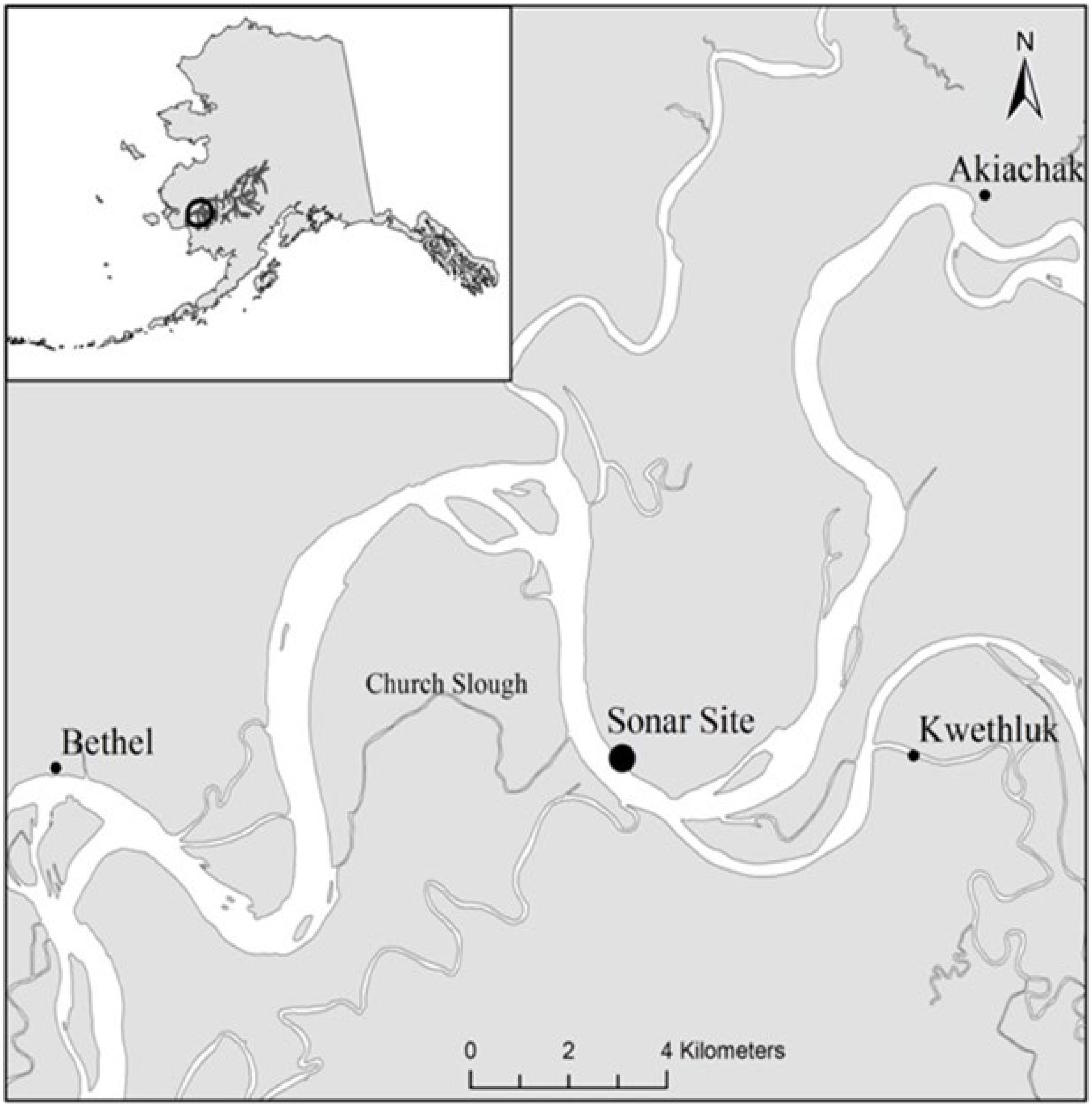


Figure 2.–Kuskokwim River sonar project site (referred to as Church Slough site).

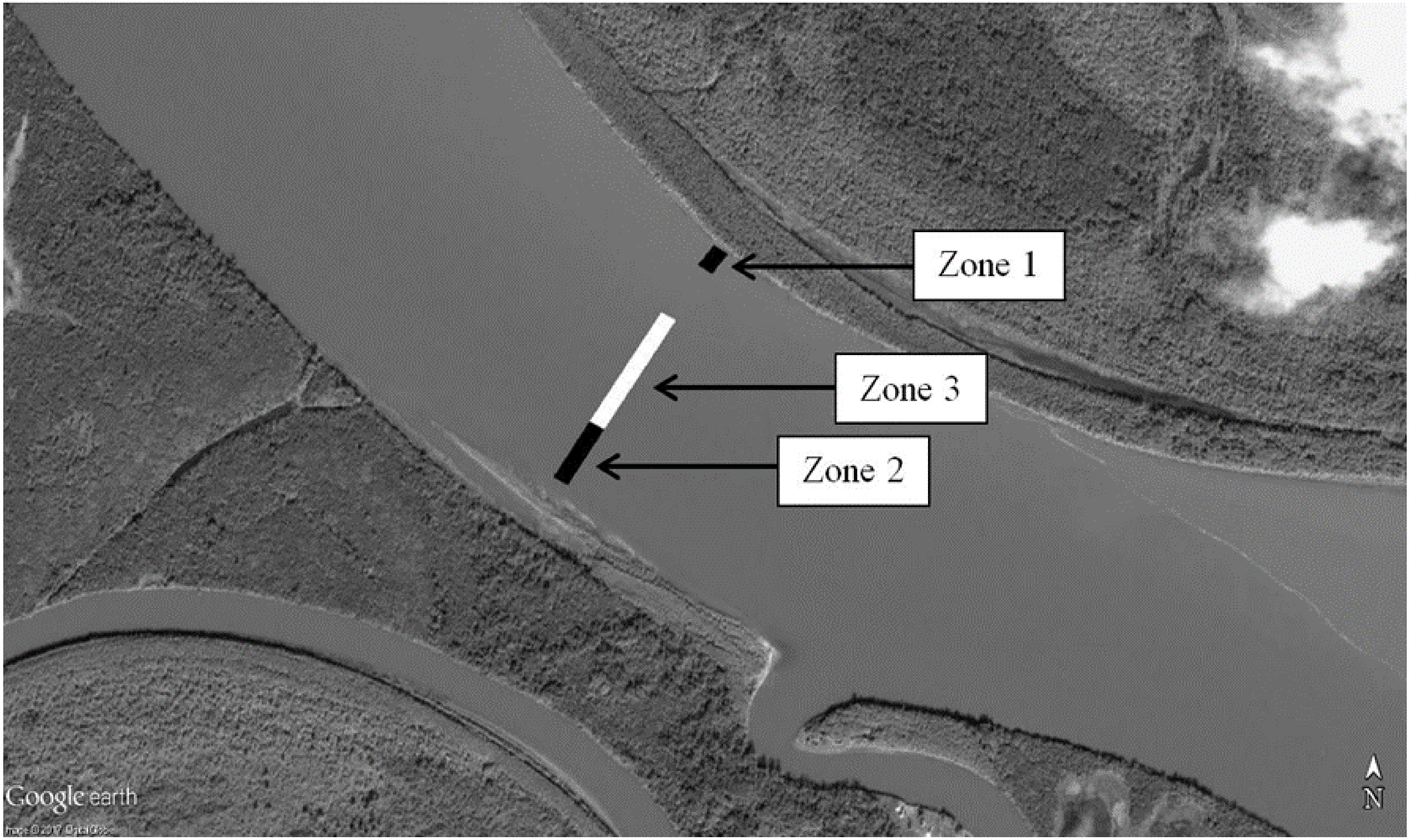


Figure 3.–Test fishery zones at Kuskokwim River sonar project, 2017.

Source: Satellite image courtesy of Google Earth, 2017.

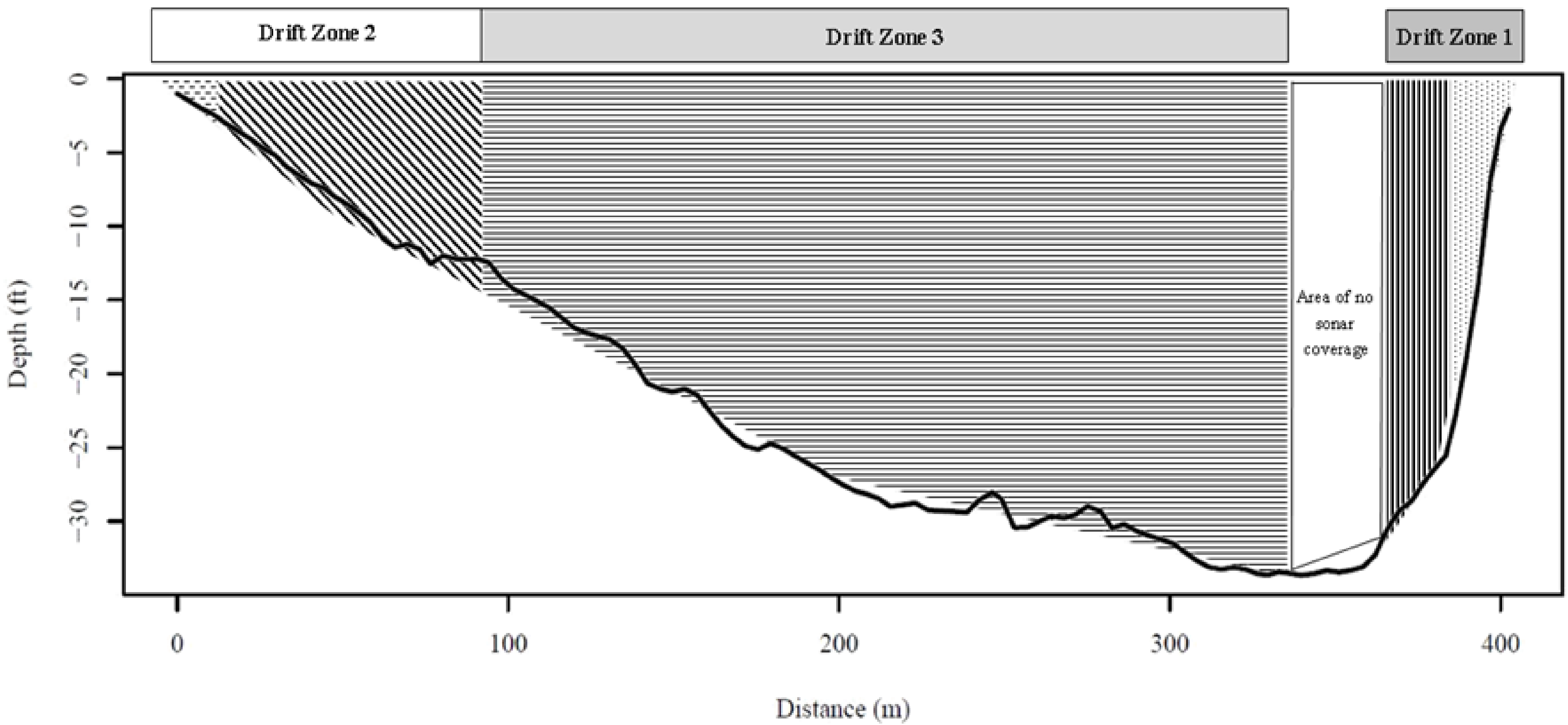


Figure 4.–Representation of the right bank nearshore stratum RS1 (dotted) and right bank offshore stratum RS2 (vertical lines) ensonified areas; left bank nearshore stratum LS1 (horizontal dashes), left bank midrange stratum LS2 (diagonal lines), and left bank offshore stratum LS3 (horizontal lines) ensonified areas.

Note: LS3 only extended to 350 m for the last week of operation. The figure includes 3 gillnet drift zones overlaid on a horizontally compressed Kuskokwim River sonar site channel profile.

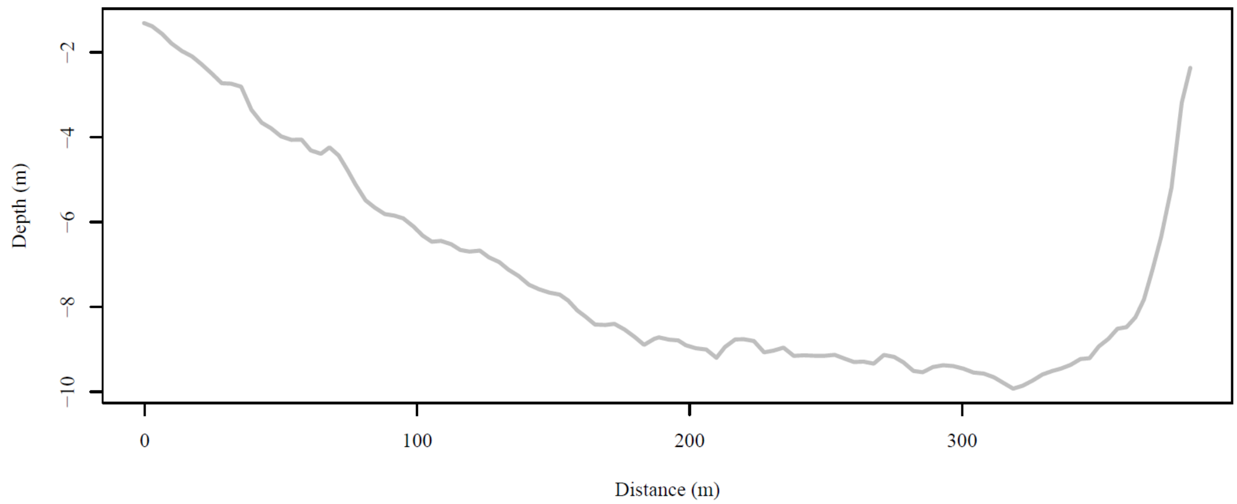


Figure 5.–Site survey at the Kuskokwim River sonar site conducted May 21, 2017.

Note: Image is laterally compressed.

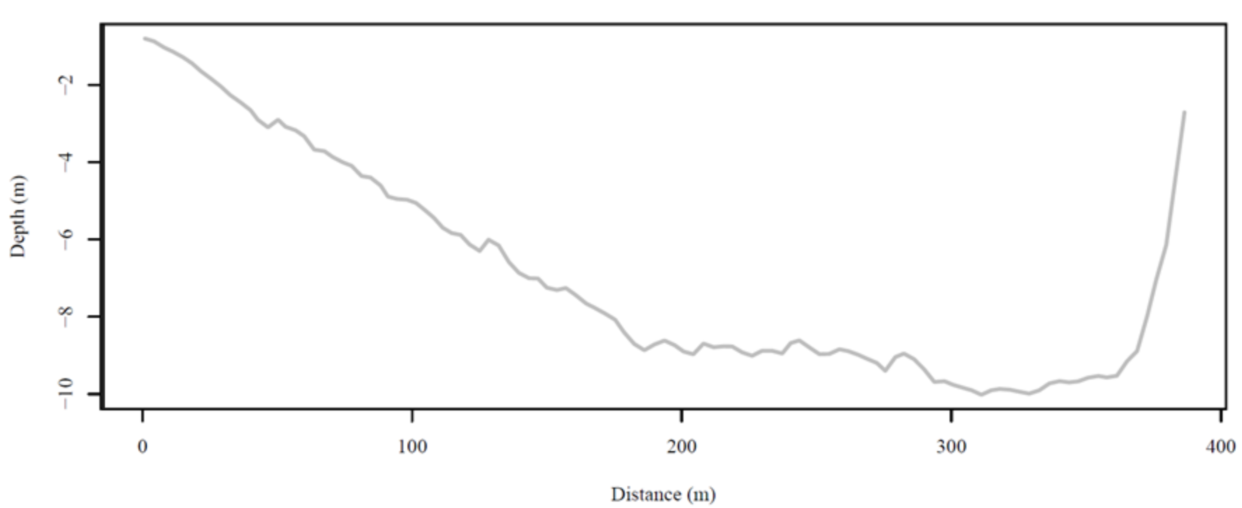


Figure 6.–Midseason site review at Kuskokwim River sonar project conducted July 10, 2017.

Note: Image is laterally compressed.

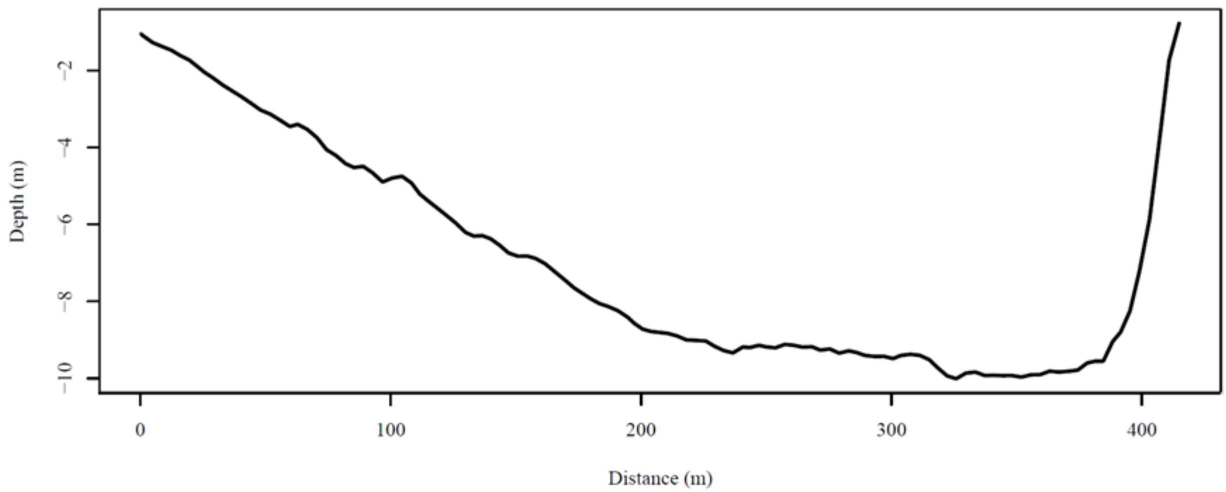


Figure 7.–Midseason site review at Kuskokwim River sonar project conducted July 12, 2016.

Note: Image is laterally compressed. Bottom relief is markedly similar to 2017 profiles.

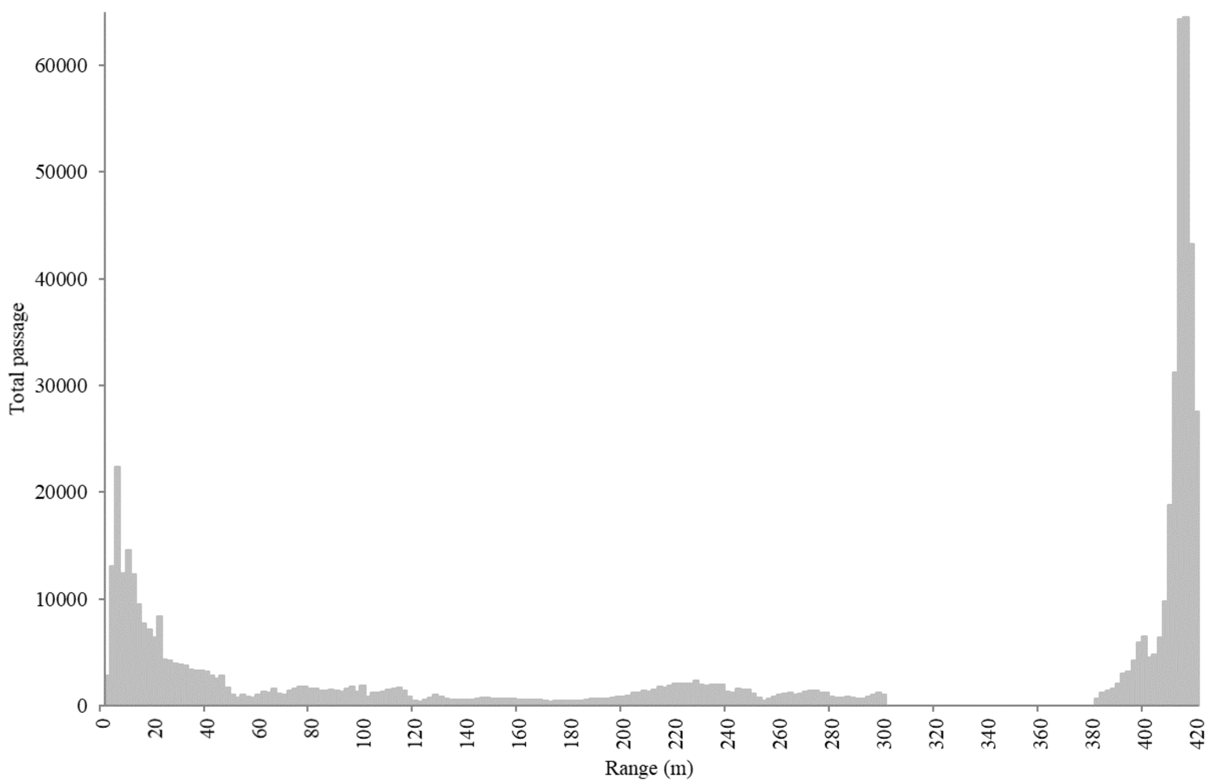


Figure 8.–Horizontal distribution of fish passage in 2 m increments, relative to transducers, at the Kuskokwim River sonar project, 2017.

Note: Median range of fish passage from the left bank transducer was 40.00 m. Median range of fish passage from the right bank transducer was 6.40 m.

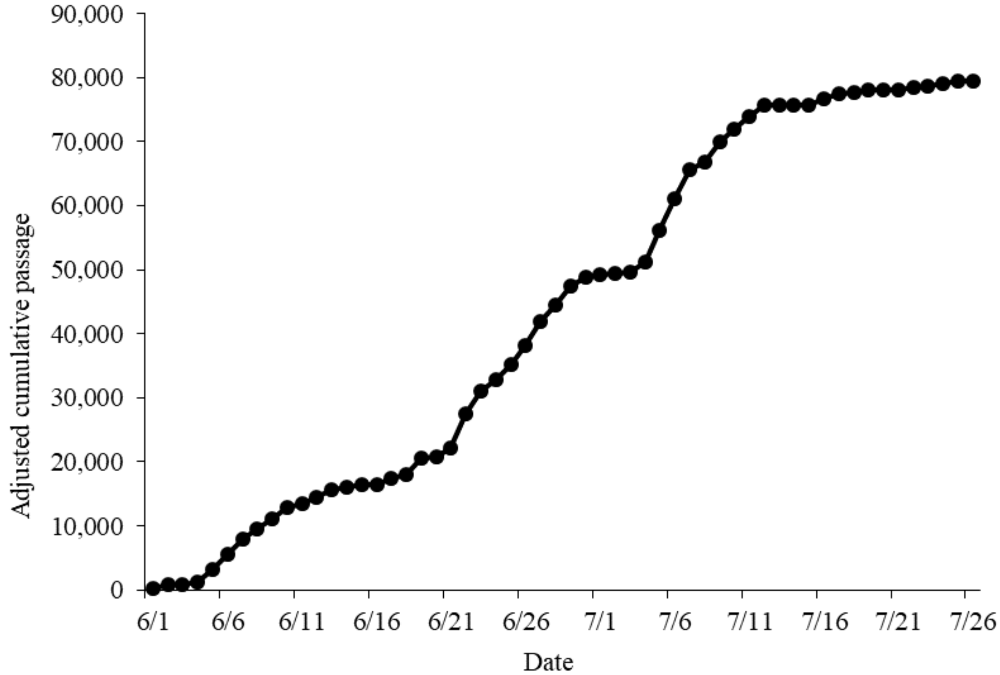


Figure 9.–Chinook salmon cumulative passage, adjusted for missed passage due to sonar downtime at Kuskokwim River sonar project, 2017.

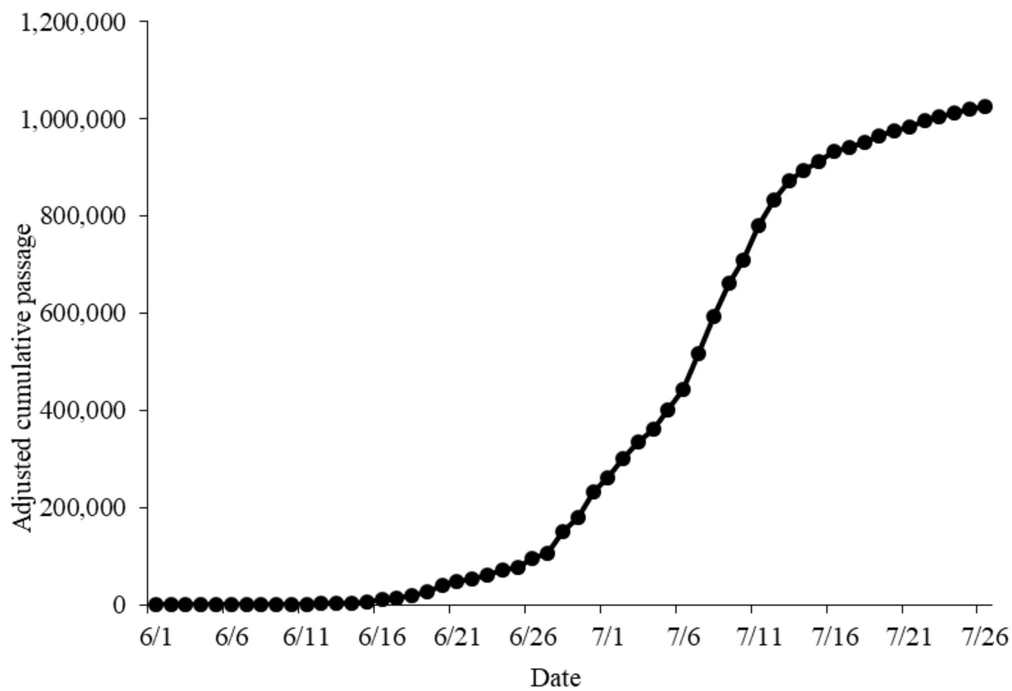


Figure 10.–Sockeye salmon cumulative passage, adjusted for missed passage due to sonar downtime at Kuskokwim River sonar project, 2017.

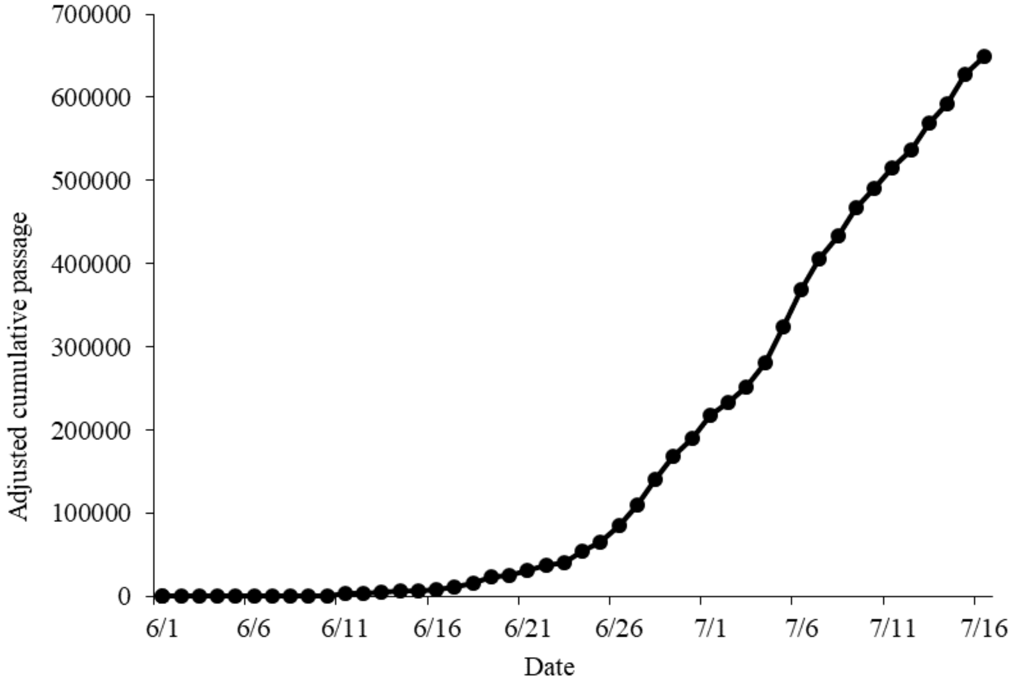


Figure 11.–Chum salmon cumulative passage, adjusted for missed passage due to sonar downtime at Kuskokwim River sonar project, 2017.

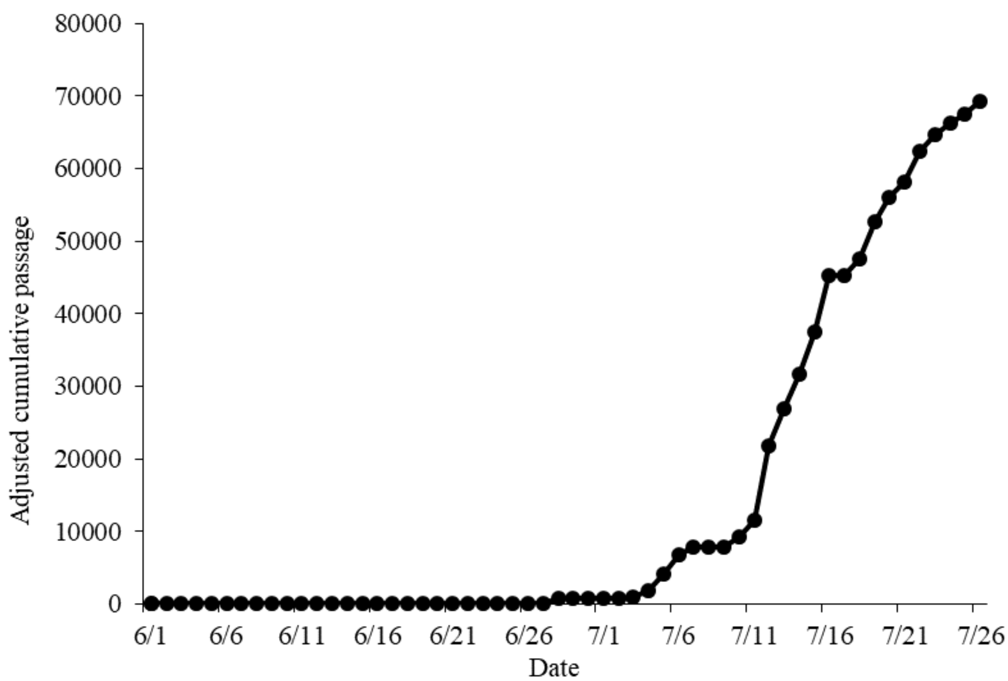


Figure 12.–Pink salmon cumulative passage, adjusted for missed passage due to sonar downtime at Kuskokwim River sonar project, 2017.

Note: Adjustment was minimal with most passage occurring after spreader lens installation.

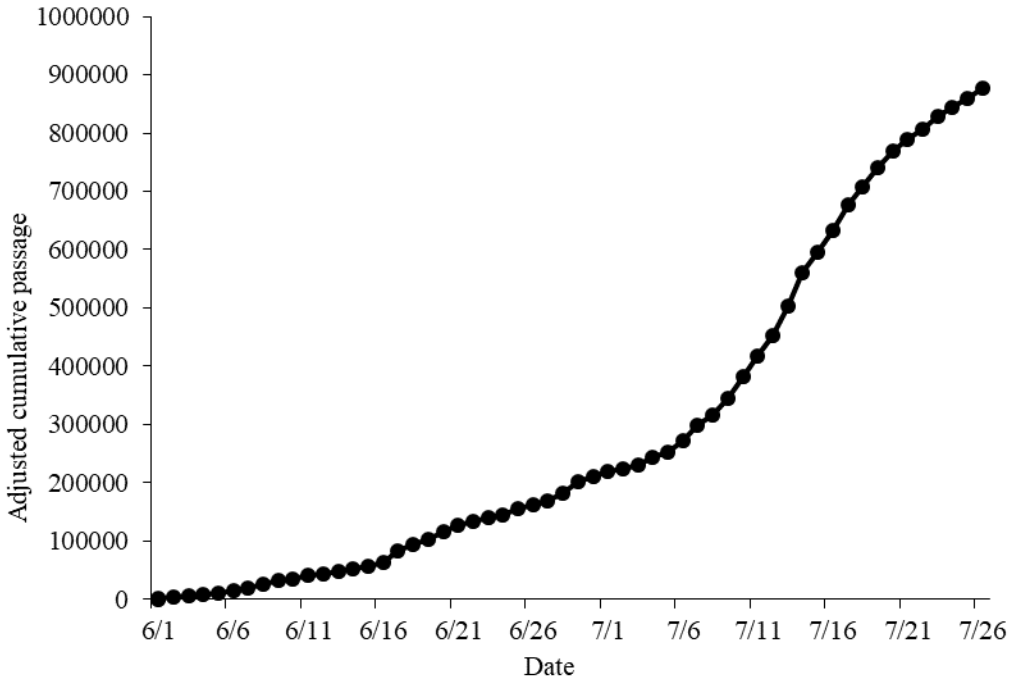


Figure 13.–Other species cumulative passage, adjusted for missed passage due to sonar downtime at Kuskokwim River sonar project, 2017.

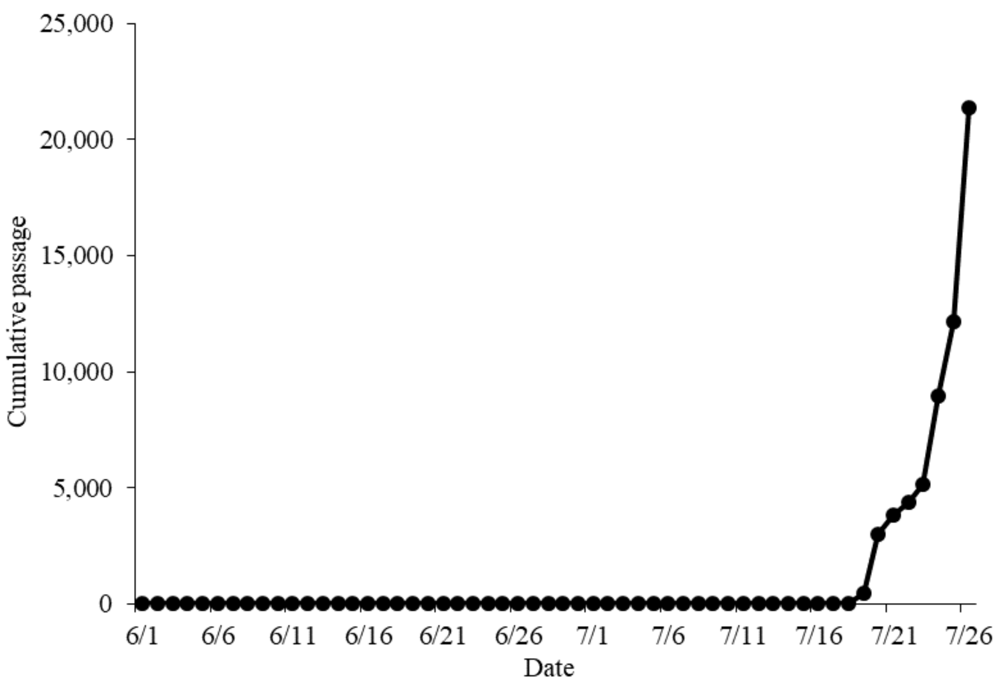


Figure 14.–Coho salmon cumulative passage at Kuskokwim River sonar project, 2017.

Note: No adjustment necessary because all passage occurred after spreader lens installation.

APPENDIX A: NET SELECTIVITY PARAMETERS

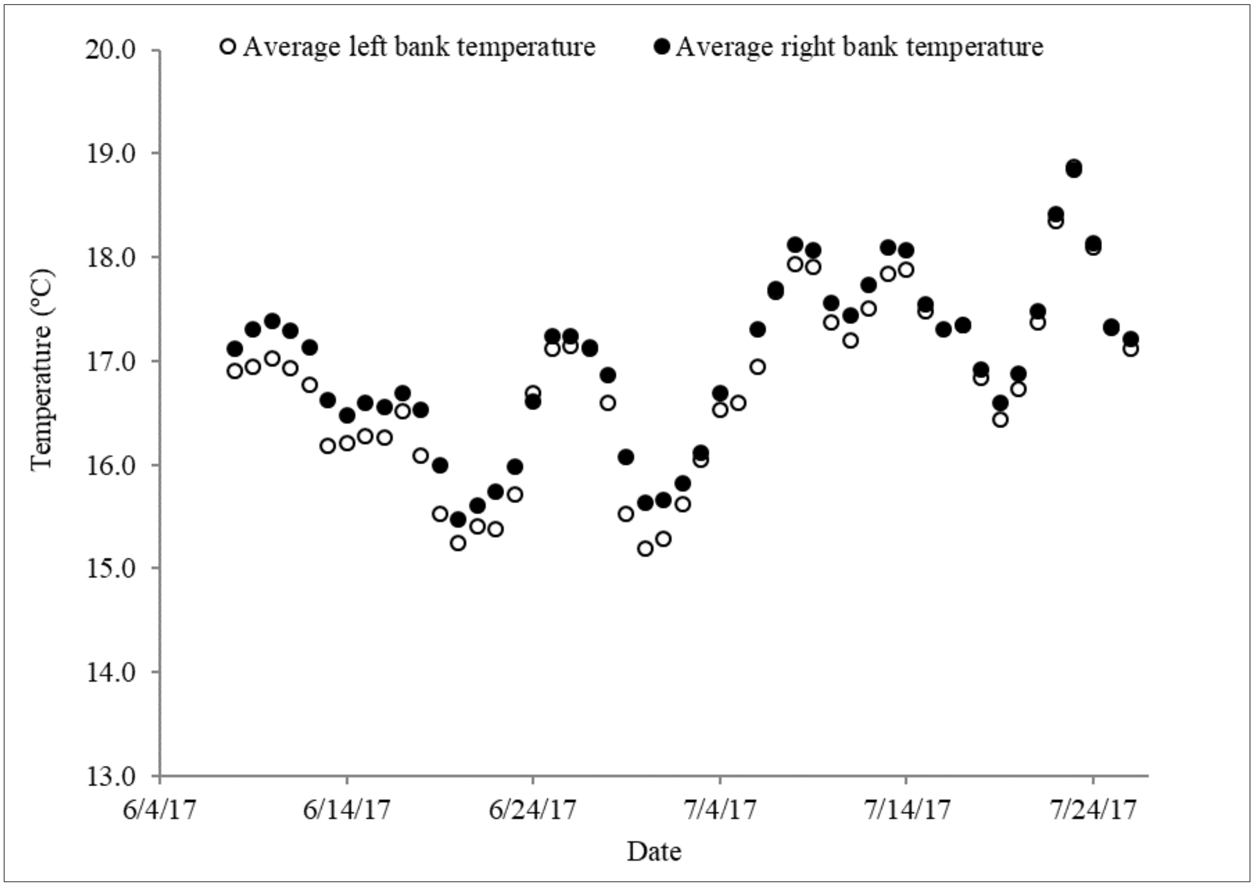
Appendix A1.–Net selectivity parameters derived from Pilot Station catch data used at Kuskokwim River sonar project, 2017.

Species	Tau	Sigma	Theta	Lambda	Tangle
Chinook	1.8873	0.1650	0.6169	-0.6916	0.0000
chum	2.0463	0.1438	0.6701	0.0104	0.0569
sockeye	2.0463	0.1438	0.6701	0.0104	0.0569
coho	1.9462	0.2869	0.7458	-1.4394	0.0000
pink	2.0226	0.1000	0.5183	-0.0294	0.0000
broad whitefish	1.8053	0.2022	0.9380	-1.5685	0.0217
humpback whitefish	1.9160	0.2444	1.0492	-1.9233	0.0373
least cisco	2.1828	0.5507	3.2351	-2.8998	0.0239
Bering cisco	2.1828	0.5507	3.2351	-2.8998	0.0239
sheefish	2.0953	0.1878	0.7310	-1.5943	0.0000
other [a]	2.2792	0.3312	0.8817	-1.4955	0.0000

[a] Includes burbot, Dolly Varden, Arctic grayling, northern pike, and longnose sucker.

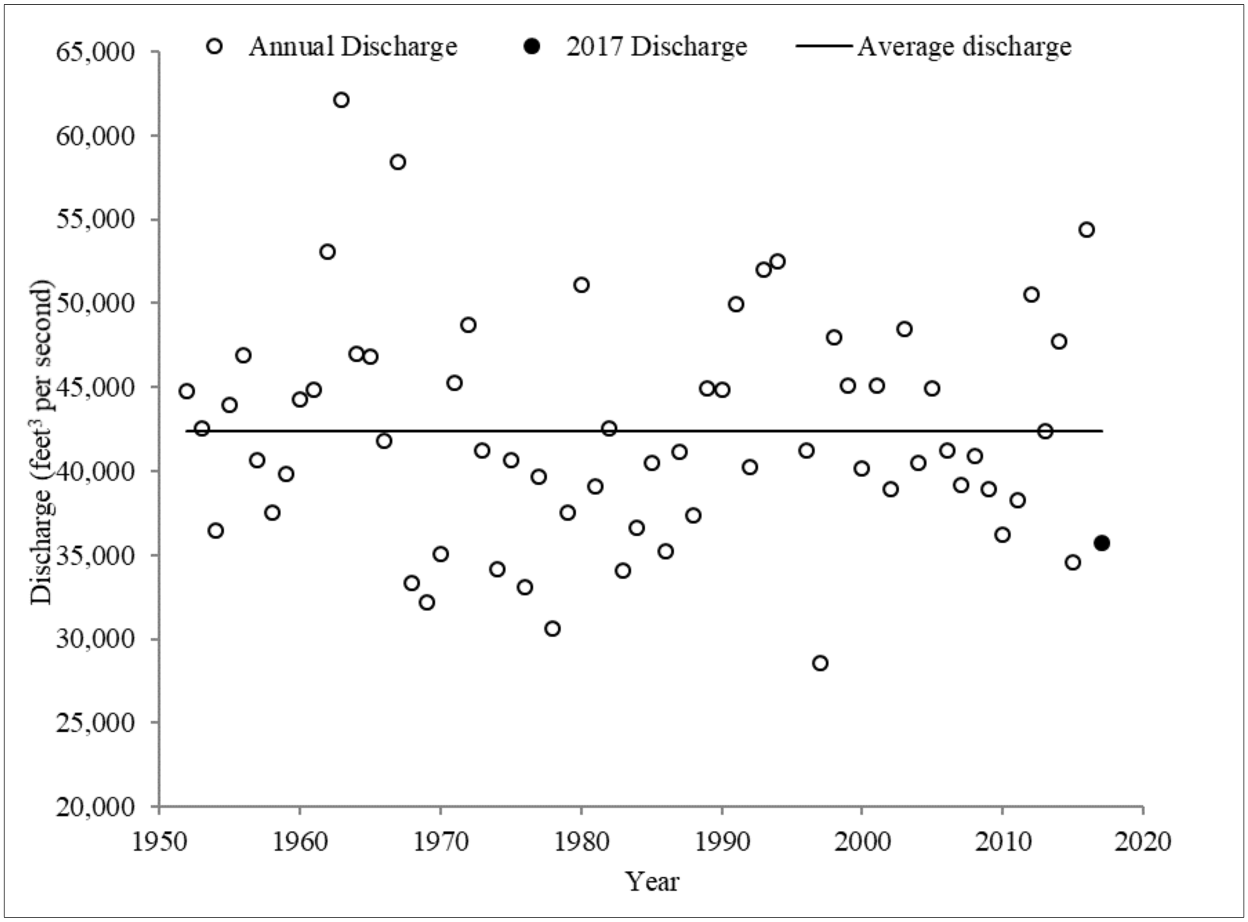
APPENDIX B: ENVIRONMENTAL CONDITIONS

Appendix B1.–Water temperature collected during test fishing operations at Kuskokwim River sonar project, 2017.



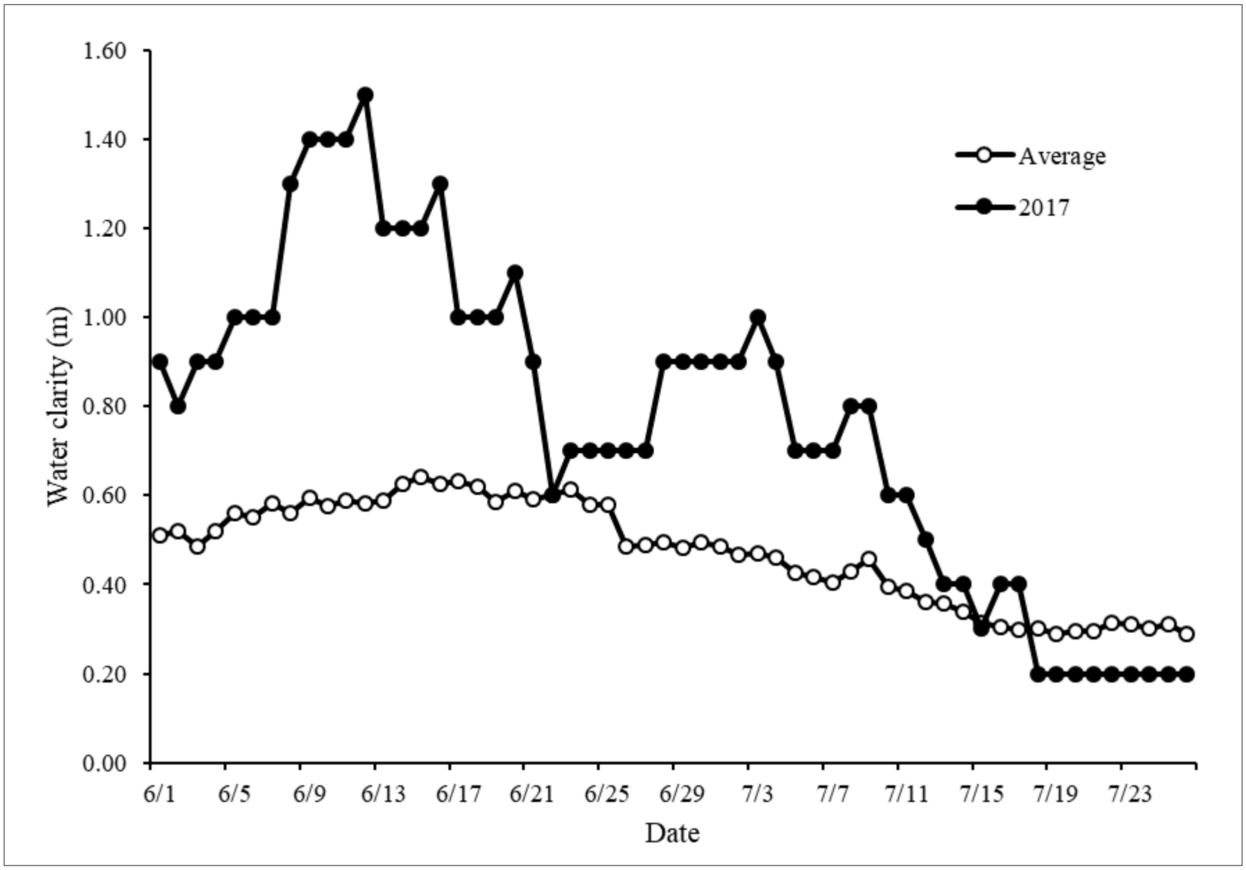
Note: Mean temperature was 16.8ºC on left bank and 17.0°C on right bank.

Appendix B2.–Graph displaying mean annual discharge rates at the Crooked Creek water gauge as an approximation of Kuskowkwim River water levels.



Note: Discharge in 2017 was below all but 10 years of the 65-year dataset and lower than 18 of the previous 20 years (USGS 2017).

Appendix B3.–Water clarity measurements collected using a Secchi disk to gauge water transparency. Data was collected by the Bethel test fishery.



Note: Figure includes 2017 measurements and mean daily measurements from 1984 to 2016.